CHAPTER 5: Operation Part 8 BURNING

THE RICE HUSK (RICE SHELL)

Rice husks, with no other practical uses of value (in this country), are a fuel with a fairly good calorific value at 10% moisture content (water basis): a HCV of 3,100 kcal/kg (5,575 BTU/pound) and a LHV of 2,800 kcal/kg (5,036 BTU/pound).

The major problem is that, when burned, they contain a large amount of ash (mainly silica, more than 20%).

The most common silica we see daily is sand. When this silica burns at the high temperatures at which the husks are burned, it forms small, semi-molten flakes with a whitish, glassy appearance; it is very volatile and abrasive.

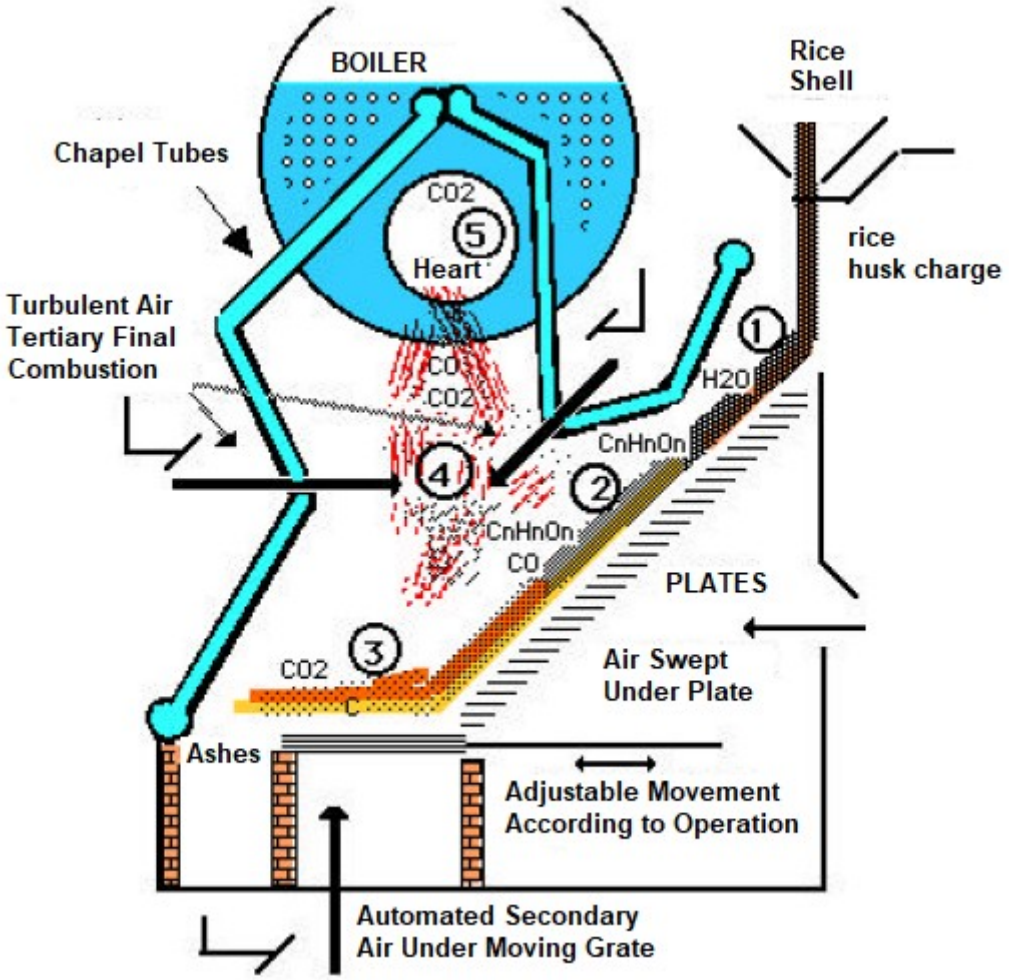
This silica is especially abrasive with the gas flow inside the boiler, causing erosion corrosion in the areas of change of front, aided when the chemical conditions of combustion are not adequate and also with the presence of a small amount of sulfur in the shell that causes an acid-abrasive type of corrosion.

The moisture content of rice husks used for burning is low, approximately 10%. This low moisture content is what makes their calorific value almost equal to that of firewood with a 25% moisture content (which rarely falls below 20%).
The carbon content is around 40%, and its hydrogen content is low, less than 5%.

As we have seen, with its calorific power, it competes perfectly with firewood, but its problem is combustion: **a large amount of ash, the husk and ash are volatile (a problem of abrasion and atmospheric pollution), but also complete combustion must be achieved, so that no unburned gases go through the chimney gases, nor does a quantity of calcined carbon remain in the ash (a black-looking ash, instead of a whitish ash).**

Its combustion has been approached in various ways: in beds (as in Uruguay), in high-temperature chambers (cyclones or torsion chambers, USA, Brazil, etc.). In Uruguay, the company TURBOFLOW URUGUAY S.A. has been building combustion bed boilers for over 20 years (6 to 10 ton/h fire-tube boilers with shrouds).

Let's look at a schematic representation of a rice husk combustion bed:



This rice husk combustion chamber consists of a combustion chamber with finned tubes (welded to the tubes) on the top and part of the sides, mechanically sealing the exhaust gases or the air intake.

These tubes are fed with boiler water at their bottom via headers (MANIFOLDS). At the top, there is one or two headers for the outlet of the circulating water and any steam that may form (this header also has steam relief tubes at its top).

At the top, it connects to the (corrugated) firebox tube, where combustion is completed inside the fire-tube boiler. The front wall and part of the back wall of its internal structure are made of refractory material (brick).

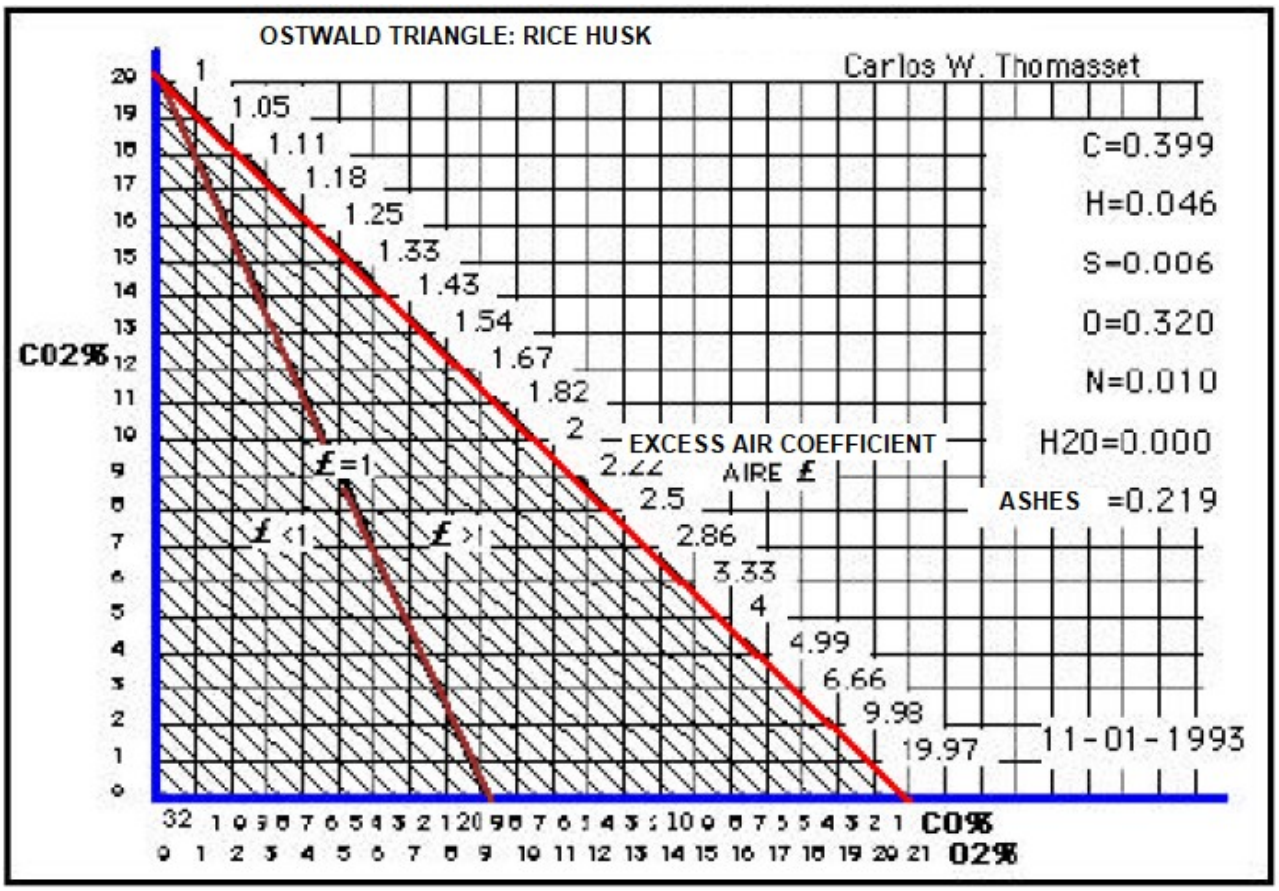
On one side is the shell loading inlet (a rotary or variable-thrust loader), which feeds an inclined grate made of cast iron plates. At the bottom, the grate consists of movable cast iron pieces (which advance the shell bed in a controlled manner, at which point it is almost ash).

At the end of the grate, there is a channel where the ash falls as the shell bed advances. Let's see how it works.

The husks are fed continuously (No. 1, according to the need to maintain a "blanket"). There is a first stage of drying the moisture from the husks with the heat of the hearth, and then, further above the hearth (No. 2) and forced by an air current that pushes the heat over the bed, this produces the release of organic gases from decomposition due to the heat (the high temperature of the hearth and a low-speed air current, which enters from below the bed, since the hearth is under negative pressure, sweeps and pushes these gases). These gases then combust (No. 4) with the remaining air and the tertiary air.

The "bed" descends as the combustion of the almost distilled "bed" continues (there is a final zone where only carbon and ash #3 remain), and after the combustion of the carbon (caused by the secondary air) only the ash will remain, this lower part of the bed being subjected to a mechanical movement that advances the bed, emptying the ash into an extraction channel.

Let's look at an OSTWALD triangle for rice husk.



In this Ostwald triangle for rice husks, we see that the maximum CO% is 32%, while in liquid fuels and natural gas it is lower. This is due to the presence of oxygen in the fuel itself.

The rice husks are considered to have already reacted with hydrogen, so what remains of the fuel is practically carbon (C). If we were to draw its Ostwald triangle, it would show a little more than 34% as CO% (carbon monoxide with pure carbon).

Combustion control must be carried out with instruments (measuring CO2% or O2% and CO%, the latter of which should be practically 0%, although this value is difficult to obtain if working with a low excess of air; this excess air is normally between 35% and 50%).

Otherwise, unburned gases appear, which have a very corrosive effect, especially due to the combination of the abrasiveness of the ash and the inherently corrosive sulfur, with other unburned gases of the acidic (pyroligneous) type.

As a practical control, the visible flame should not extend beyond one-third of the combustion chamber, thus ensuring complete combustion.

Flue gases must undergo a treatment process to remove entrained ash (otherwise, the area is contaminated with volatile silica).

A significant problem is the disposal of the ash (which is almost 90% silica). While it is used in some smelting furnaces, other uses are not yet applicable in Uruguay.

Rice husks are a fuel that should not be wasted, but unfortunately, as a residue, they are burned in the open air, and their energy value is not utilized. In Uruguay (as of 2011), only a couple of parboiled rice mills use them.

Some Portland cement kilns have used them, adding extra heat (and the resulting ash, to a certain extent, can be incorporated into the Portland cement mixture).

BURNING OF FOREST CHIPS AND WASTE IN GASIFIER BOILERS

The burning of forest chips and waste has increased in the last two years for use in boilers to generate electricity (either for direct sale or for use in cogeneration plants: generating electricity and process steam).

Wood chips and husks have been used in direct-fired boilers for many years.

Now, we are in a stage of using gasifiers (something that has not yet been adequately resolved in Uruguay; we are talking about 2009-10). Gasifiers have flat grates and are counter-current.

The wood chips enter from the top, the gases also exit from the top, and the primary air enters from below where the flat grate is located and where the ash is supposed to fall. In some cases, this is combined with the burning of sawdust blown into the torsional chambers themselves (which are attached to the gasifiers for secondary combustion).

A short-loose log gasifier, when gasifying, produces gases with temperatures ranging from approximately 450°C (842°F) to 700°C (1292°F). This causes tar cracking, preventing the formation of tar deposits that can cause fouling and combustion problems in the system (clogging gas valves, forming deposits that block the duct between the gasifier and the torsional chambers, etc.).

However, when burning wood chips and sawdust, the combustion tends to become incomplete within the gasifier, leading to the distillation of the wood (or biomass waste). This is evident in the low temperature of the gases exiting the gasifier, which generally rarely exceed 200°C (392°F).

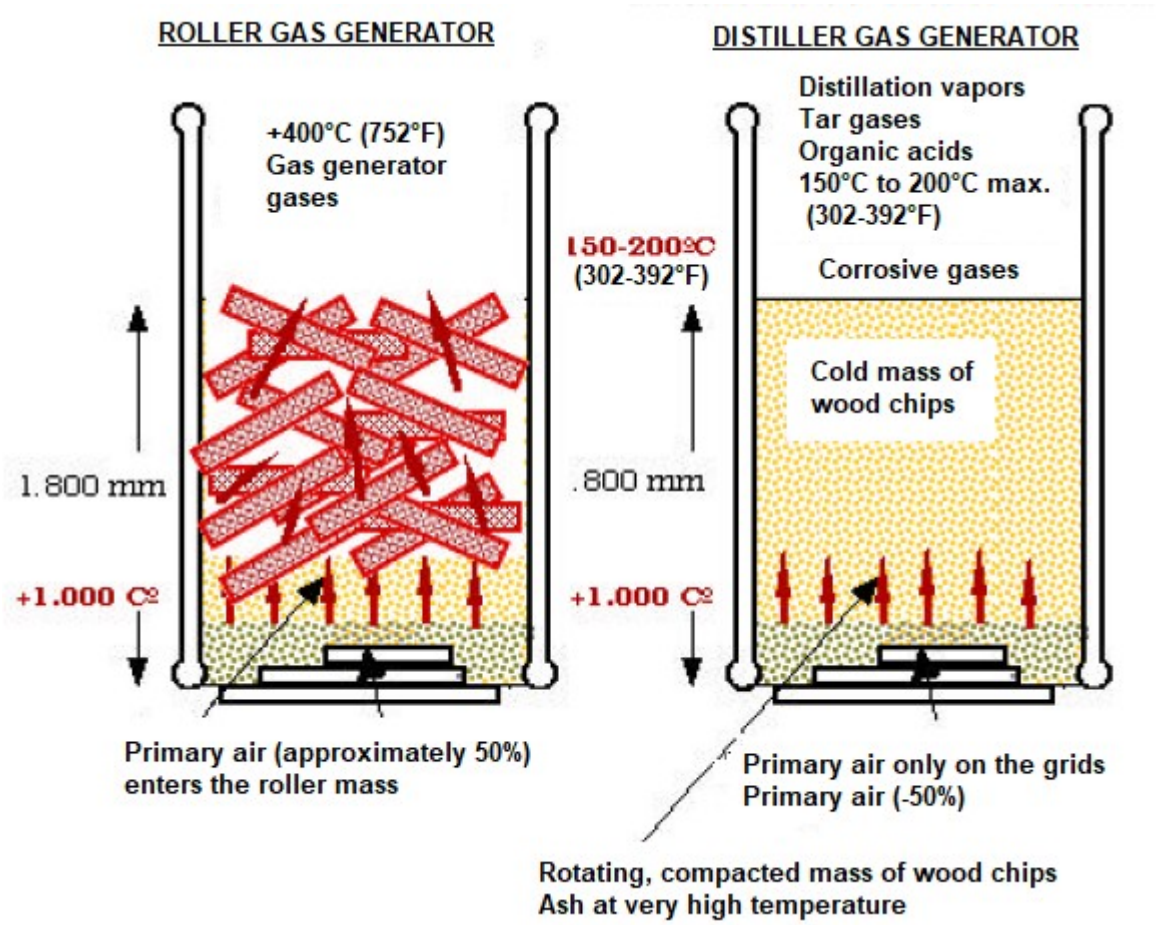
These "dirty" tar gases are composed of many distilled elements, some of which are very easy to burn, but pose a risk of explosion (organic gases of different composition). **When cold and containing tar, although difficult to burn when cold, they can easily explode due to their high flame speed (methane, alcohols, pyroligneous materials, etc.).**

When short logs are burned, although the operating procedure is the same, the falling logs do not "smother" the combustion. Primary air enters and heats up between the logs, reaching temperatures above 450°C (842°F). This causes the tar and other components to crack, forming other compounds that are more manageable for combustion control.

Gas-fueled boilers that burn logs rarely require liquid fuel burners as "pilots" to maintain the gas flame.

However, when burning wood chips and sawmill waste, it is unthinkable to operate at startup without a powerful burner to ignite and sustain the flame of the cooled gas from the distilled wood chips until the combustion chamber is properly heated.

We believe that this difficulty can be overcome by introducing primary air into the mass of chips, so as to produce greater combustion and thereby raise the temperature in the "mass" of chips and thereby cause a "cracking" of the organic molecules into gasifier gases and decrease the presence of tars and other heavy molecules.



ROLLERS STOCKS VERSUS CHIPS IN GAS GENERATORS

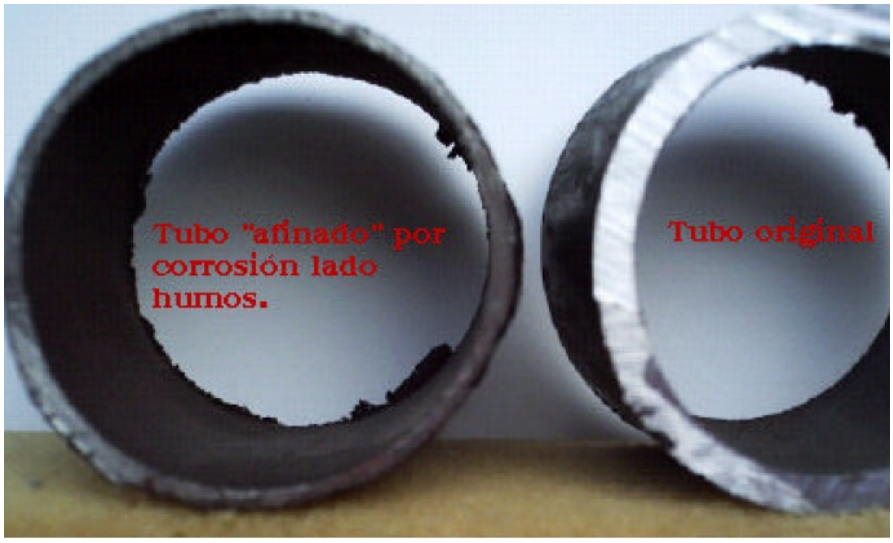
To avoid having to stop the gas generator when the "neck" of the connection between the gas generator and the torsional chamber becomes "blocked" (due to the accumulation of tar and solid materials, such as partially burned wood chips, etc.), the height of the chips is lowered (losing combustion capacity for gas generation) to raise the temperature to values that can burn these deposits.

Personally, I believe this is a problem if the temperature exceeds 750°C (1382°F), as it means the gasifier is vaporizing (its heat transfer increases because its exchange surfaces are exposed to a larger area and a higher temperature).

This high vaporization can cause the difficulty of steam removal to the boiler, reducing the cooling capacity of the water entering the gasifier. This is because the water's circulation depends on a very small difference in height for the "siphon" effect, and since 1 liter (dm^3) of water produces several liters (dm^3) of steam, the expulsion or removal of the steam with this increase in volume prevents the gasifier from operating flooded with water.

The upper part would operate flooded with steam, which absorbs little cooling heat from the gasifier's head tubes, causing high-temperature corrosion on the fire side. Added to this are the problems of expansion and contraction due to the disparate temperatures... metal can have.

Let's look at some tubes in the "head" of a gas generator that, due to exposure over time to such hot gases and also with the probability of attack by pyroligneous acids, the presence of CO (carbon monoxide) at high temperature attacks the metal.



LEFT: Corrosion-repaired flue pipe – RIGHT: Original (new) pipe

The formation of stones on the grill, a result of the high temperature of localized horizontal combustion, not only causes the wood to distill, producing tars and corrosive gases with a high risk of explosion,

but also results in the formation of "ash stones" from the ash that melts at a relatively low temperature (this situation can be improved by using magnesium oxide, which raises the ash's melting point).

A relatively inexpensive solution is the use of dolomite (ground into powder), which is composed of approximately 30% magnesium carbonate and 70% calcium carbonate. At high temperatures, both decompose into their respective oxides, raising the ash's melting point, as mentioned.

If these stones form, there comes a point where the gasifier must be stopped and removed; otherwise, the gasifier will cease to operate correctly (the rotating grate will jam, the air inlets will become blocked, and fuel capacity will be reduced).

It is also not advisable to operate the grate without a layer of ash, as this would expose it to high temperatures due to the "forge effect" produced by the air entering at high speed and impacting the burning material, raising the metal to very high temperatures and causing rapid corrosion.

Rotating plates at the bottom of the gasifier for ash removal and primary air intake.

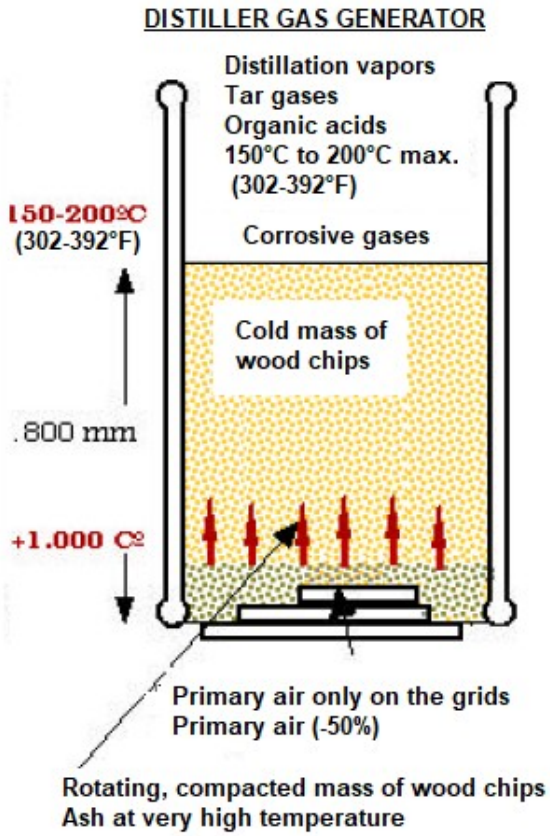
Wood chips become compacted due to poor combustion caused by excess air localized in channels.

This localized air raises the temperature, melting the ash and leaving other sections without air, which then fails to combust and becomes compacted.

The mass of chips tends to rotate on the rotating plates that form the chip support grid; this is one of the factors that allows the "clumping" of the chips (due to the lack of mobility between chips and the presence of tars). The air inlets between plates tend to become clogged, and the primary air is almost relegated to that which enters through the sides of the larger plate against the gas generator.

Perhaps this can be resolved by arranging refractory steel retaining elements to hold the rotating mass of chips, and these retaining elements should be angled to loosen them.

In reality, nothing has been done to remedy this situation so far, except to minimize the chip load. This improves the temperature of the gases formed (reaching almost 400°C/752°F), but complicates the handling of the gasifiers due to the small amount of residual fuel in combustion, requiring careful management to maintain the chip level.



las

Stones formed from ash,
due to the "forging effect" produced by the air.

The formation of chips wood tar is not only a problem of its complete combustion in the torsional chamber (especially if it is cold or if the biomass has a high moisture content), which causes poor secondary combustion that results in premature fouling of the boiler's heat exchange surfaces, but also causes corrosion in the hot and cold zones.

But the other problem with tar is the "clogging" of the safety guillotine valves for the isolation of the gas generators with the torsional chamber, guillotines that must respond quickly to a secondary flame failure problem, although this has been improved by putting high-power hydraulic pistons and also the injection of steam in the most problematic areas.

Wood tar is formed by the low temperature of the gases at the gasifier outlet.
It behaves like a wood still.

The formation **of "ash stones" is not exclusive to gas-fired boilers; it can also occur in direct-fired boilers** when the "forge effect" is **caused by a "poor grate design"** (such as grates formed only by the tubes).

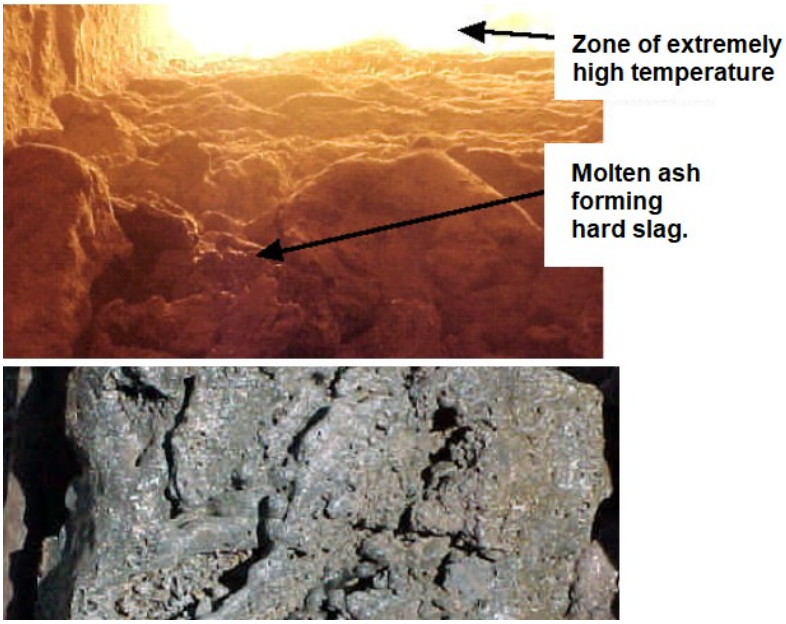
It's important to remember that grates are not only for supporting the burning logs, but also for ensuring proper air distribution in contact with the burning wood.

This prevents areas where air doesn't flow evenly and areas where air enters only in specific spots, causing the "forge effect"—that is, a flame of extremely high temperature, as if it were in a forge.

Let's look at a photo.

The air enters an area that generates a high temperature,
which can overheat the tube without cast protection.

Stone formation in direct-fired boilers is not only due to the "forge effect," but can also occur if very low moisture content fuel is used (pellets with less than 10% moisture). Let's look at this:

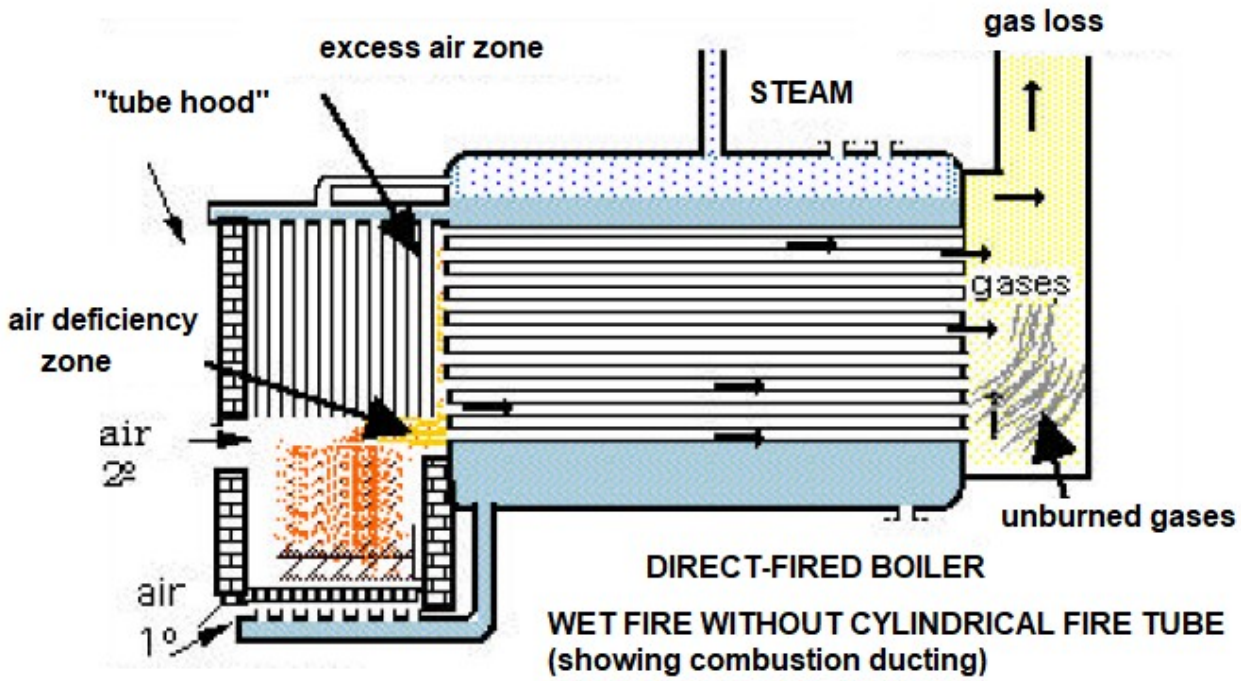


Photographs of "molten" ash forming a hard slag, and of dragged ash blocking the steam blower of the convective bank within a few hours of operation.

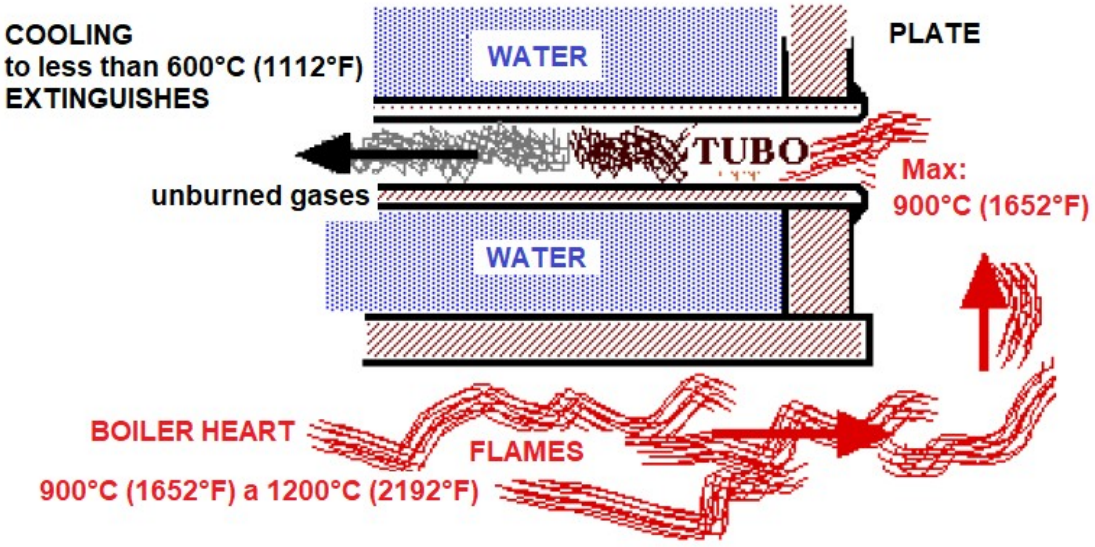
The major problem with burning such dry pellets on an unsuitable grate is that it can lead to the destruction of the moving grates, since the resulting stone has the hardness of lava (molten rock), which obstructs their movement.

There may even be volatiles from this molten lava that are deposited on the boiler tubes as they are carried by the gases and condense on the relatively cool surfaces of the tubes.

PROBLEMS IN FIRE-TUBE BOILERS WITHOUT A FIRE TUBE



Another problem with "direct combustion" is when the boiler is designed without a combustion tube, because if complete combustion does not occur before the combustion gases enter the tubes, these incomplete flames are extinguished upon entering the tubes and quickly foul them (producing a "tube" of ash that restricts the passage of gases, which increases the problem of poor combustion and the fouling process, resulting in a significant loss of energy as "unburned gases").



There is a "belief" that the cast iron grates that go over the cooling tubes of the grate in direct-burning chimneys are to "hold the logs" (rolls), and this is not actually the case.

The cast iron grates have such a shape and distribution that their primary function is to distribute the "primary" or "under-grate" air so that the air is correctly distributed among the burning biomass.

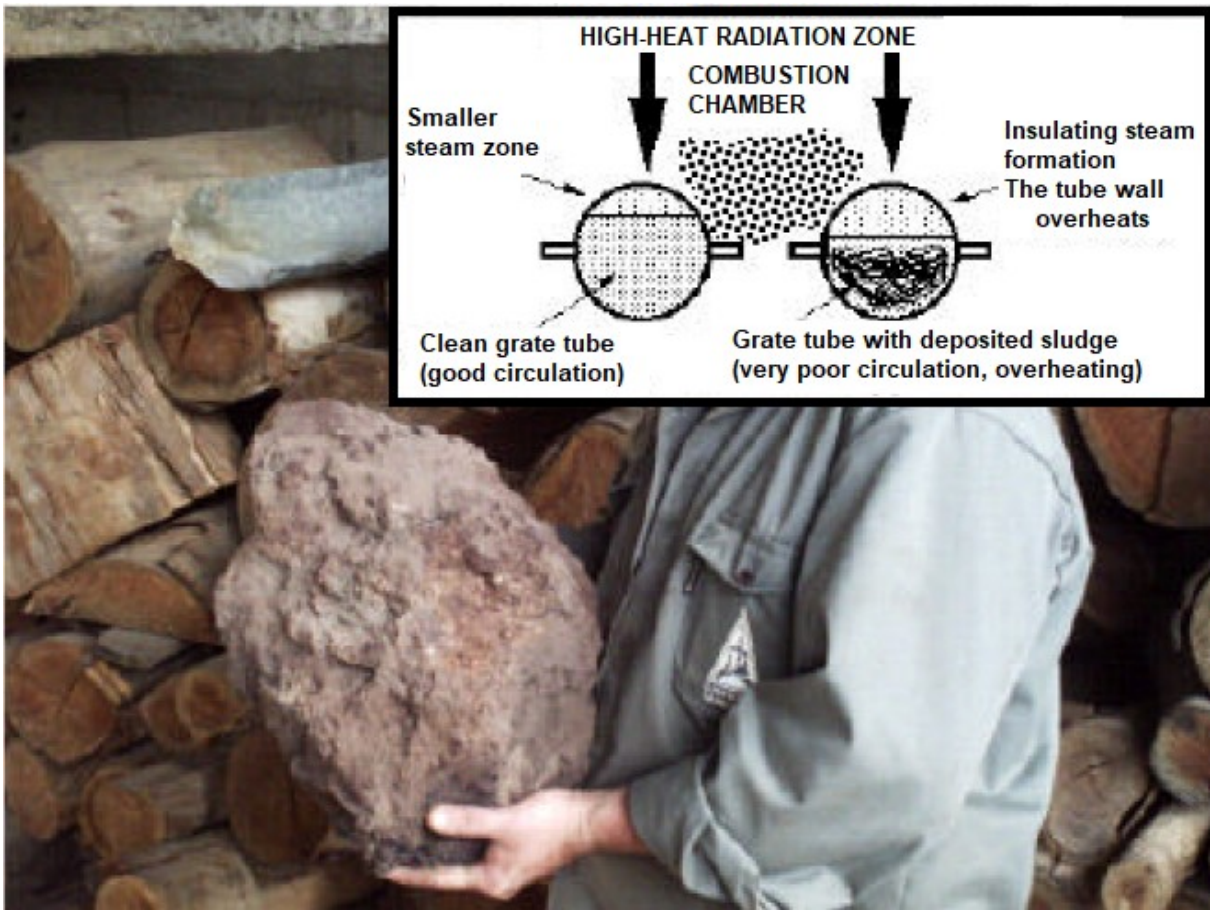
When these "cast iron grates" are replaced by the simple support offered by pipes spaced apart, the airflow becomes uneven.

In some areas, the pipes, resembling a funnel, block the passage, trapping ash and preventing airflow. In other areas, excessive air enters, creating a "forge effect" (excessive air leading to high temperatures and the formation of "ash stones").

Let's look at a "ash block" formed by the previous boiler, which lacks a primary air distribution grid.

It only has combustion support tubes through which boiler water circulates. However, this allows the "forge effect" to easily develop as part of the area between the tubes becomes blocked by the conical shape formed between two tubes.

Meanwhile, in other areas, the combustion blanket remains "perforated" by the primary air impacting it like a forge (producing a high temperature that melts the ash, as shown in the following photo).


HIGH-HEAT RADIATION ZONE
COMBUSTION CHAMBER
Smaller steam zone
Insulating steam formation
The tube wall overheats
Clean grate tube (good circulation)
Grate tube with deposited sludge (very poor circulation, overheating)

The grate becomes "covered" after a few days, and significant ash accumulations form due to the high temperature developed in the perforated area of the covered grate. There is a risk of tube overheating.

The formation of "ash stone" is not exclusive to the burning of very dry biomass; it can also occur depending on the origin of the biomass (for example, eucalyptus and pine forests near the sea have a high salt and sand content, with the sand clinging to the bark, especially in pines).

However, they can also be the source of the biomass, as is the case with firewood from natural forests (hardwood, very old, with a very high salt content).

Although burning firewood from natural forests is expressly prohibited to conserve them, it is no longer advisable to use it in a boiler, since the resulting ash stone has the hardness of glass (a very hard lava); it cannot be broken with a crowbar, the boiler must be stopped, and the grates must be cleaned by hammering, which is not recommended.

DESIGN AND ADAPTATION PROBLEMS OF WOOD-FIRED BOILERS

The design and adaptation of wood-fired boilers requires extensive experience in handling wood-fired boilers.

While it's generally thought that wood-burning boiler problems are solely related to combustion, this isn't the case. Wood (or biomass) boilers typically require combustion chambers attached to new or existing boilers, whether they are direct-fired or gas-fired.

The most common mistake is a lack of understanding of the internal water circulation system, whose function is not only to supply water for steam production but also to cool the heat transfer surfaces.

Remember that at the same pressure (saturated steam temperature), the volume occupied by a mass of water is much smaller than the volume that mass of water would occupy once transformed into steam (the lower the boiler's operating pressure, the greater this difference).

For example, if the boiler operates at 10 kg/cm² (142 PSI), the volume of 1 liter (1 dm³) of water, upon evaporation, transforms into 180 liters of steam (180 dm³). If the boiler operates at 50 kg/cm² (711 PSI), 1 liter (1 dm³) of water, upon evaporation, transforms into 39 liters (39 dm³) of steam.

But let's remember that water is much better at cooling heat exchange surfaces than steam (which behaves more like a gas than a liquid). The steam bubbles that form in saturated water absorb a large amount of heat (due to the latent heat of vaporization), but it is the presence of water alongside the steam bubbles that "wets" the surface and improves the heat transfer coefficient, and it is the steam that forms where that large amount of heat goes.

The problem is that if we "put" a volume of water into a direct-burn combustion chamber or a gas generator (or torsional chamber), we must remove a quantity of water and steam with a much larger volume due to the formation of said steam.

This is done by means of the "evaporator" tubes (or "ventilation" tubes, or return tubes to the boiler at the top of the combustion chambers).

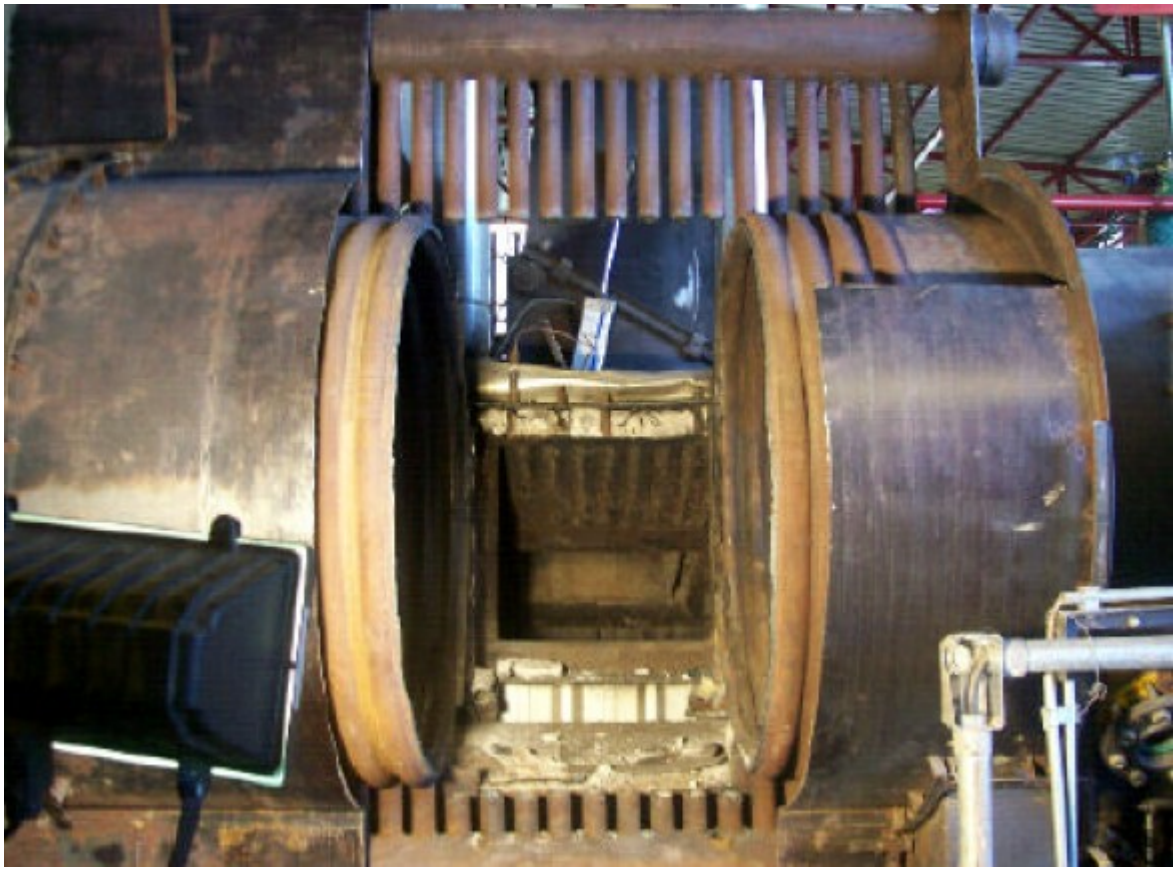
The problem arises when the return tubes ("evaporators") are insufficient at high combustion rates to extract all the evaporated water.

The resulting flow creates a pressure drop (like a steam plug) that prevents enough water from entering to cool the tubes in the drums or gasifiers (or torsional chambers).

And since steam has a lower capacity to absorb heat, it causes the tube walls to overheat, leading to wear from high-temperature corrosion or even burning.

This problem is exacerbated by water conditions (high pH, high salinity, contaminants that alter the water's surface activity, such as grease, oil, etc.) or if the surfaces to be cooled have any scale buildup.

This problem can be identified through two observations or measurements. The first is the fluctuation of water levels, and the second is placing a surface thermometer to measure the temperature of the return tubes (or steam tubes) to the boiler.



TORSIONAL GAS GENERATOR CHAMBER WITH CIRCULATION FAILURE

Add approximately 15°C to 20°C (68°F) to account for heat loss from the tube wall. Observe whether this temperature is above that of saturated steam, indicating "superheated" steam.

This means that the upper part of the combustion chamber tubes is cooled only by steam, which raises the tube wall temperature, causing wear due to high-temperature corrosion.

In some cases, the return tubes release bursts of water and steam, causing water carryover into the boiler steam. This occurs because the discharge impacts the boiler's water separators, which are generally insufficient to separate the water and steam under these conditions.

Wood-burning boiler conversions are the most dangerous if the internal circulation, or cooling of the heat exchange surfaces, is not respected.

The case we will show below didn't even reach the working pressure, and the boiler's combustion chamber "collapsed" due to lack of cooling.

While it wouldn't pass inspection from a structural standpoint, it at least withstood the hydraulic test pressure. **However, in the first attempt to build steam pressure through combustion, it collapsed before reaching the working pressure (7 kg/cm², 99 PSI), causing an expansion that propelled the boiler's front 85 meters. The people who were starting the boiler were seriously injured.** Let's look at the photo.

In the case above, if we look at the water inlet from the boiler to the combustion chamber, which is a water collector of no less than 4 inches, the discharge at the top consists of three 1-inch "boiler" tubes.

If we consider that when 1 liter (1 dm³) of water flows down, it evaporates into 277 liters (dm³) of steam at 6 kg/cm², displacing the water from the adapted combustion chamber into the boiler body, the pressure at which the boiler

furnace opened like a "sardine can," causing a very violent expansion that nearly resulted in the deaths of several people, in addition to material damage that is insignificant compared to the loss of human life.

The risk of "adaptations" is greater because they generally involve people who do not have sufficient knowledge of the subject and what can happen; it is not just about putting water in but about how to remove that partially evaporated water and that if it has no outlet the steam "pushes" the water making it back towards the boiler, which makes the furnace work without cooling water.

EXPLOSION OF A HOMO-TUBULAR RECOVERY BOILER